Adam Mickiewicz University in Poznan

Doctoral School of Exact Sciences AMU

Modelling and Data Analysis for Physicists and Engineers using MATLAB and COMSOL Multiphysics.

Dr Thomas Vasileiadis

Field of science	Physics
Teaching method	Lectures and hands-on training in computer laboratory
Language	English
Numbers of hours	15
Aims of the course	a) Learn how to use MATLAB for automatic data analysis, visualization and curve fitting. b) Learn how to solve ordinary differential equations with MATLAB. c) Understand and simulate physical systems governed by ODEs. d) Gain conceptual and practical knowledge of the finite element method (FEM). e) Simulate and analyze real physical phenomena (plasmonics, mechanical vibrations, phononics) using COMSOL Multiphysics.
Course contents	Week 1: **Data Loading and Plotting with MATLAB.** Importing data (text, CSV, Excel), plotting 1D/2D data, subplots, log/log plots, export options. Hands-on: Plotting experimental spectra and time-domain data. Week 2: **Curve Fitting and Data Analysis.** Least squares fitting, fit, polyfit, lsqcurvefit, residual analysis, confidence intervals. Fit of an exponential decay, Gaussian or Lorentzian peak to experimental spectra. Week 3: **Solving Ordinary Differential Equations (ODEs).** The ode45, ode23s, and stiff solvers; initial value problems; parameter scans. Examples: Damped harmonic oscillator, driven systems. Application: The two-temperature-model (TTM) of electron-phonon coupling. Week 4: **Analyzing Dynamical Systems.** Phase space plots, fixed points, bifurcations, Lyapunov exponents (intro), MATLAB animations. Example: Predator-prey systems. Week 5: **Introduction to the Finite Element Method (FEM).** Concept of discretization, elements, nodes, boundary conditions, solving PDEs. Week 6: **Plasmonic Resonances with COMSOL RF Module.** Basics of plasmonics, metal-dielectric interfaces, solving Maxwell's equations, resonance conditions. Dipolar plasmon resonance in a metallic nanoparticle, i.e., nanosphere or nanorod. Week 7: **Spherical Lamb Modes – Eigenmodes of nanospheres.** Elasticity, spherical symmetry, eigenfrequency analysis. Vibrational modes of a nanoparticle: quadrupolar modes, torsional modes, breathing modes. Mechanical coupling in nanoparticle dimers. Week 8: **Phononic Band Structures of Nanomembranes and 2D phononic crystals.** Periodic structures, Bloch periodic boundary conditions, band structure calculations, dispersion relations.

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<tr><td>Prerequisites and co-requisites</td><td colspan="2">a) Basic programming skills.
b) Basic knowledge of classical mechanics and electrodynamics.
c) Willingness to read documentation and tutorials online.</td></tr>
<tr><td colspan="3">Learning outcomes</td></tr>
<tr><td colspan="2">On completion of the course PhD candidates will be able to:</td><td>Assessment mode</td></tr>
<tr><td colspan="2">E_W02 and E_W03: Ability to import and visualize data with MATLAB, and to plot multi-dimensional data in addition to 1D plots.
E_W02 and E_W03: Ability to import, preprocess, and fit data with the least squares method, and to analyze the goodness of fit, residuals, and confidence intervals. Ability to automate this process and to provide a transparent, reproducible analysis.
E_U01: Ability to solve ordinary differential equations with MATLAB, and to apply this knowledge to model systems such as the driven damped harmonic oscillator and the two-temperature model of heat transfer.
E_U01 and E_U03:Ability to analyze the behavior of dynamical systems using phase space plots, bifurcation analysis, and basic stability concepts. Understanding of dynamical systems in society and nature, like the predator-prey system.
E_W01 and E_W02: Understanding of the basic principles of the finite element method (FEM), and how FEM is used to solve partial differential equations with appropriate boundary conditions.
E_W02: Ability to use COMSOL Multiphysics to simulate and analyze plasmonic resonances in nanostructures, solving Maxwell’s equations for metal-dielectric systems. Explore phenomena related to plasmonic coupling between nanostructures.
E_W02: Ability to compute and interpret elastic eigenmodes of nanoparticles, including breathing, torsional, and quadrupolar modes. Explore phenomena related to mechanical coupling between nanostructures.
E_W02: Ability to calculate phononic band structures in periodic systems using FEM, apply Bloch boundary conditions, and plot dispersion relations.
E_W02: As a final project, the students will learn how to use MATLAB or COMSOL for their research project.</td><td>Weekly Assignments (40%)

Final Project (40%) – If possible, related with their thesis.

Active participation and engagement (20%)</td></tr>
<tr><td>Literature</td><td colspan="2">1) "Essential MATLAB for Engineers and Scientists" by Brian Hahn and Daniel T. Valentine.
2) COMSOL Documentation (User’s Guide & Application Libraries)</td></tr>
<tr><td>Additional information</td><td colspan="2">1) Official MATLAB Documentation – MathWorks
2) MATLAB Onramp (Free interactive course)
3) File Exchange & MATLAB Central
4) COMSOL Learning Center, COMSOL Blog & Community Forum</td></tr>
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